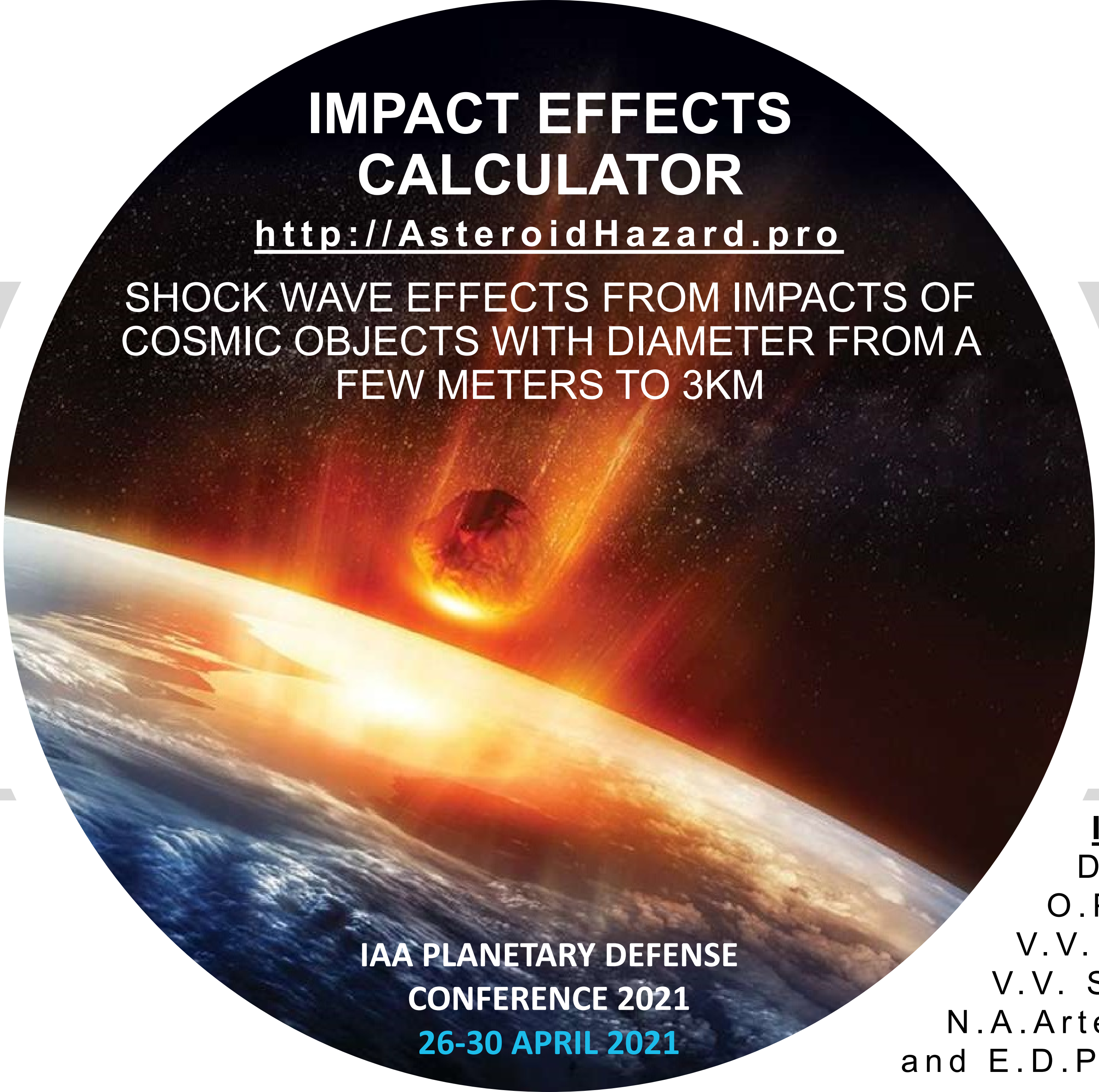

# IMPACT EFFECTS CALCULATOR

http://AsteroidHazard.pro

## SHOCK WAVE EFFECTS FROM IMPACTS OF COSMIC OBJECTS WITH DIAMETER FROM A FEW METERS TO 3KM

IAA PLANETARY DEFENSE CONFERENCE 2021

26-30 APRIL 2021


IDG RAS

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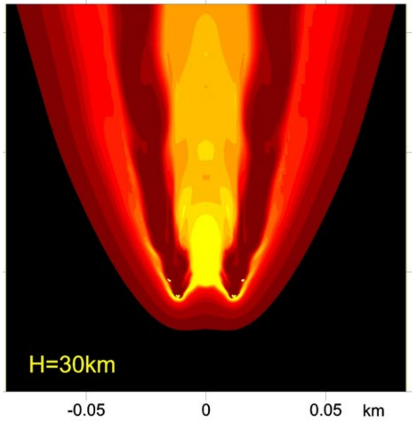
N.A.Artemieva,
and E.D.Podobnaya

# Motivation

*Physical process*

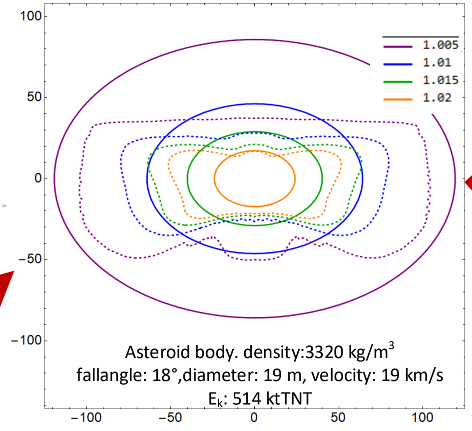
*impossible for a full − scale laboratory experiment*

*Modeling*



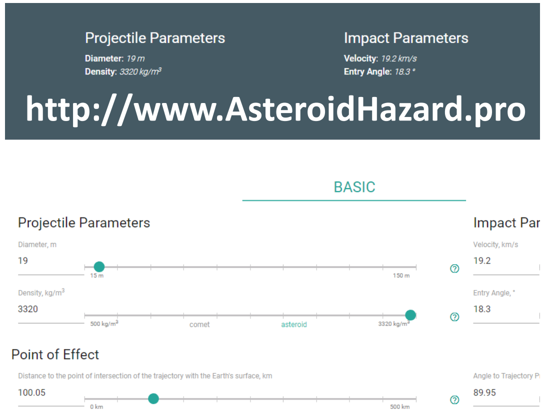

*slow calc*

*Scaling relations*




*quick calc*

*online calculator*

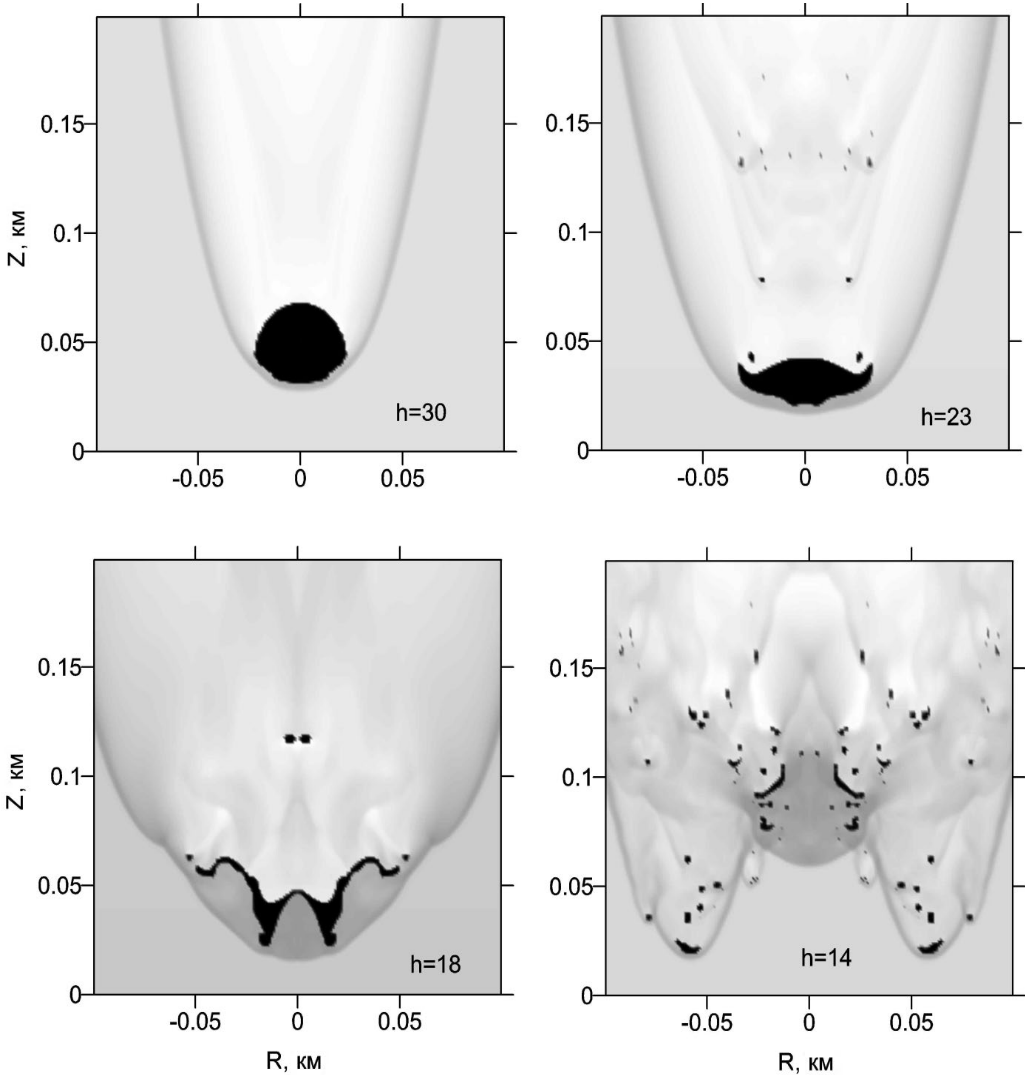



*easy to use*


***

The main motivation is to create a quick and accurate tool for assessing the consequences of the impact of a cosmic body.

# Quasi-liquid meteoroid model




Relative density distribution along trajectory at different altitudes h
D=40 m, V=18 km/s; chondritic material (2650 kg/m$^3$), α=90$^0$
Black – solid meteoroid material

## Basis:

large meteoroid deformation begins at h, where aerodynamical loading>>strength

## Main assumptions

- Zero strength
- Ablation as evaporation
- Radiation transfer in thermal conductivity approximation

## Formal range

D>30-50 m; h<40 km (Svettsov et al. 1993)

## Restrictions:

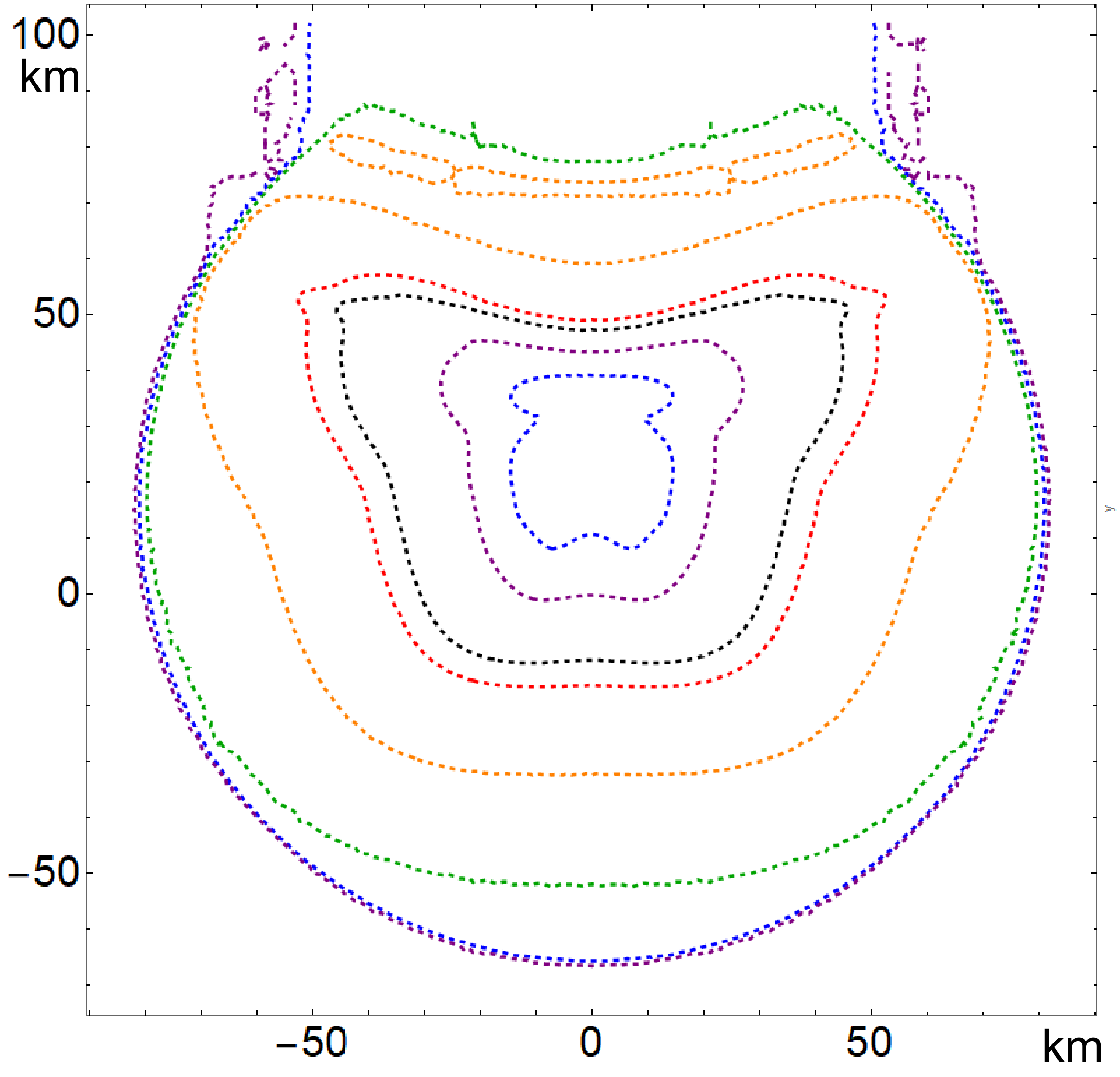
quasi-liquid assumption

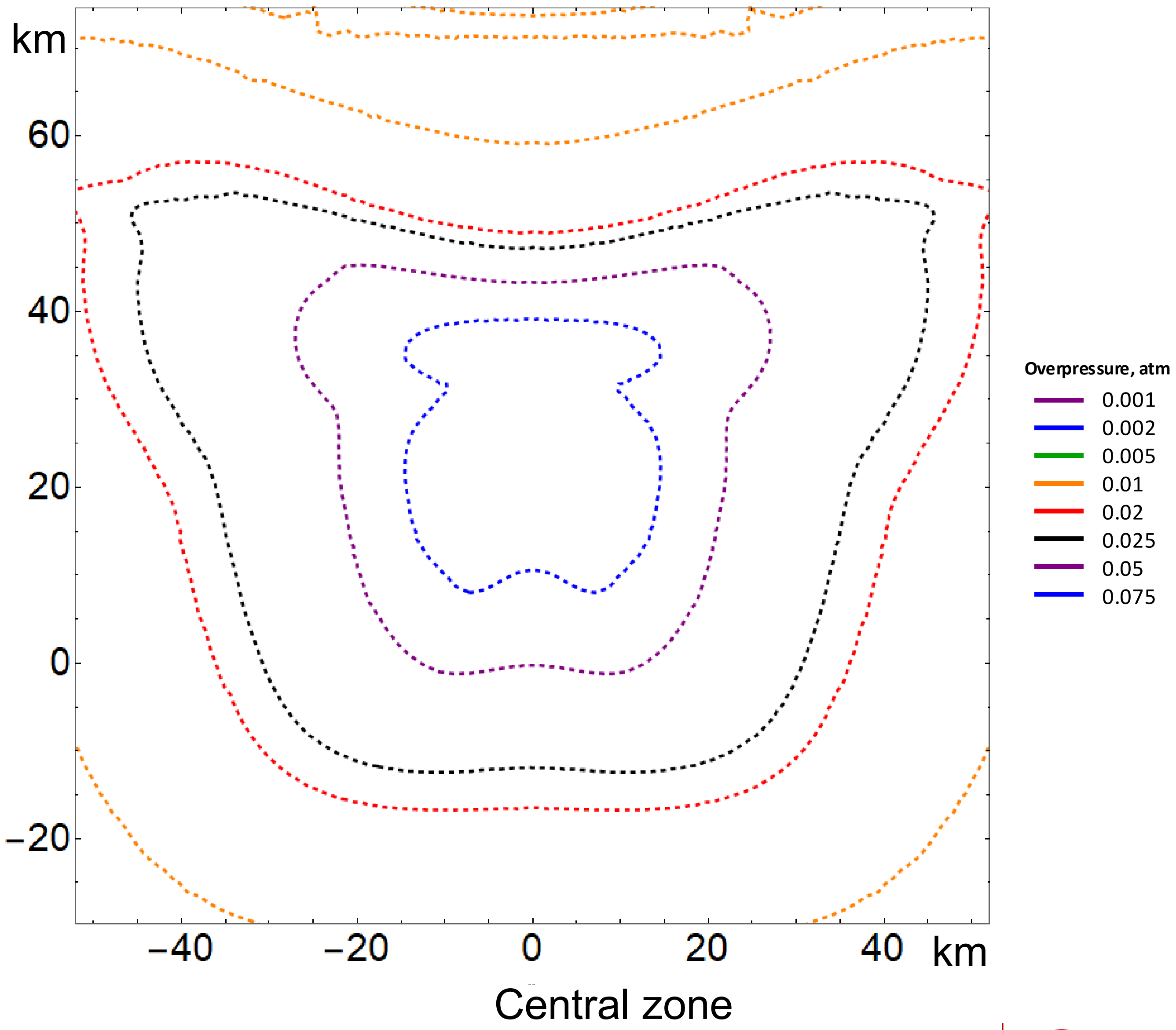
Quasi-liquid model= QL model

# D-30-45-20

density: 3320 kg/m$^3$
diameter: 30 m

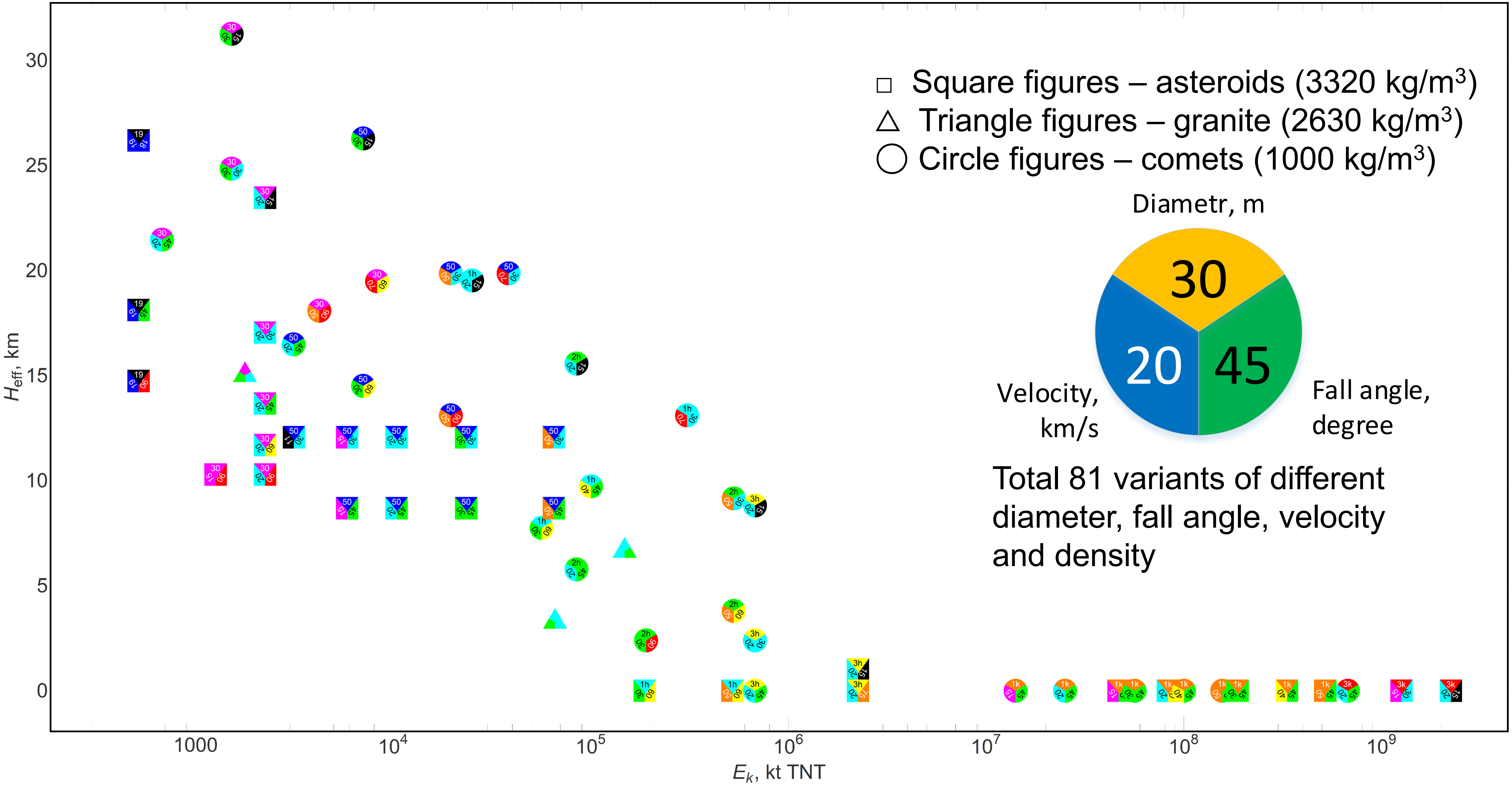
entry angle: 45°
velocity: 20 km/s



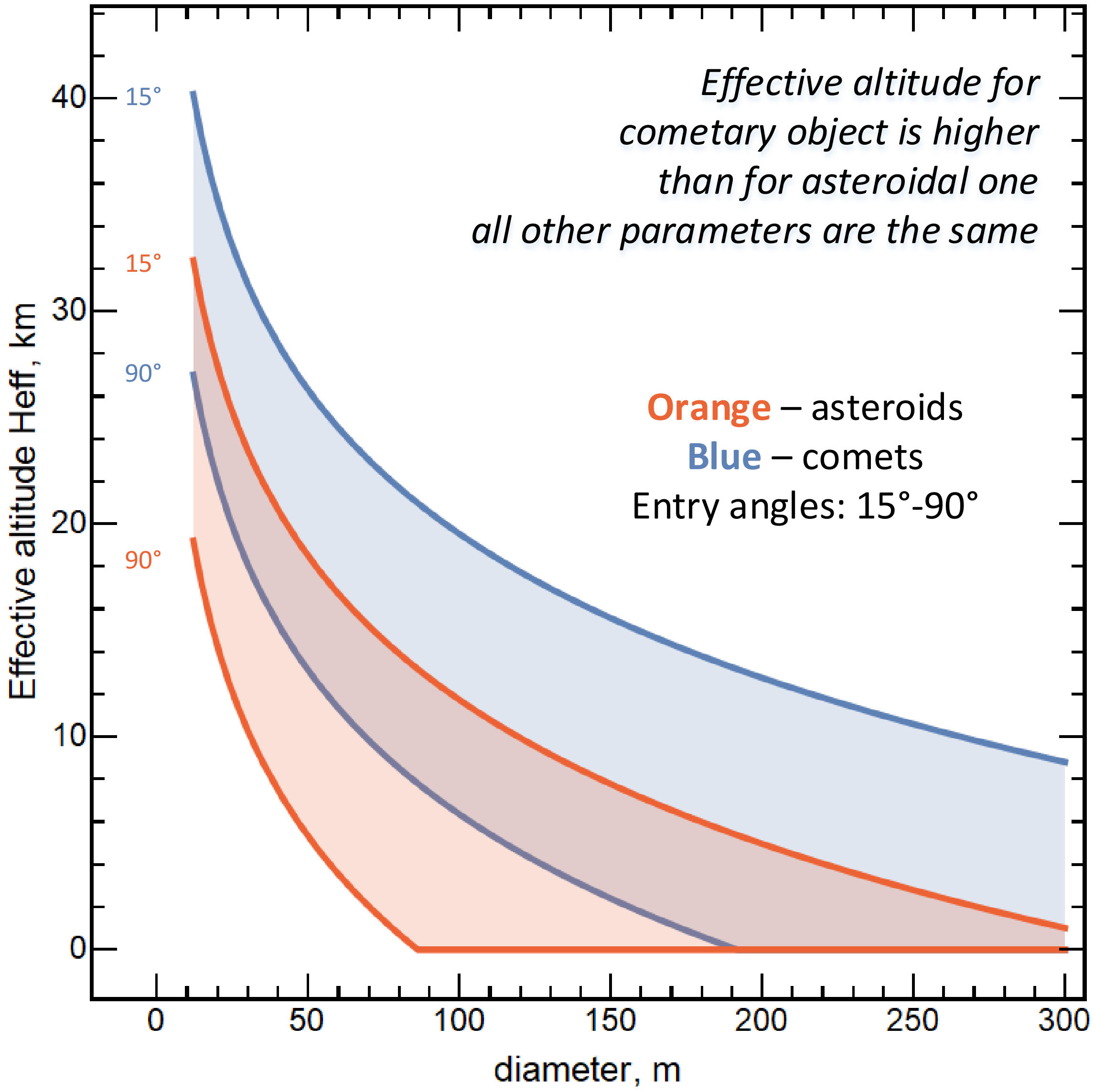

Overpressure distribution obtained for one variant

# Modeled variants




Total 81 variants of different diameter, fall angle, velocity and density

# Effective airburst altitude




Effective altitude dependence on meteoroid size

$$H_{eff} = (-1.3 * H * \mathrm{Ln}(D * (\mathrm{Sin}[\alpha]/H) * (\rho/\rho 0)^{2/3}) + H)/1000$$

For quick rough evaluation of the impact consequences (levels of damage, area of the damage, etc) at large distances from the ground zero spherical source - reasonable SW evaluation if the altitude Heff of E-equivalent point explosion is correctly determined

QL model was used to determine Heff =f(D,density,α) (Shuvalov et al. 2016)

This approach:

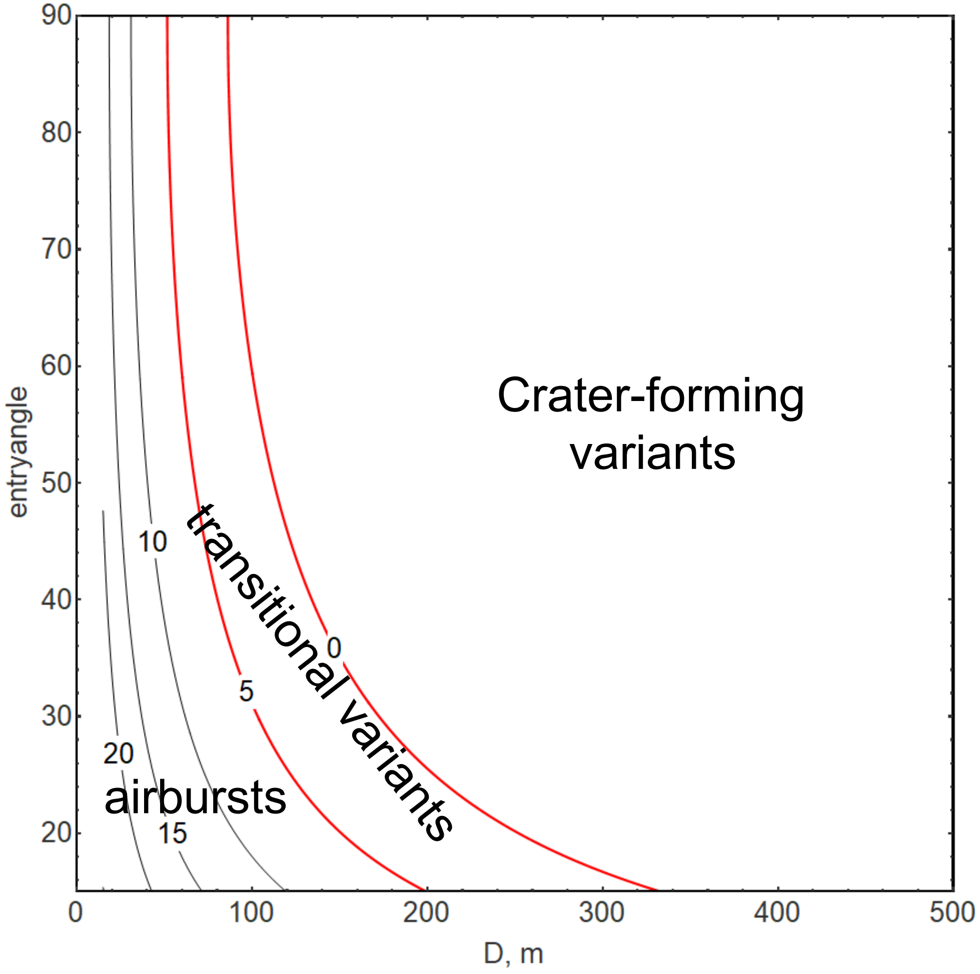
-Precision of estimates - 2-3 km (random character of disruption)

-Is applicable for D>10-30 m

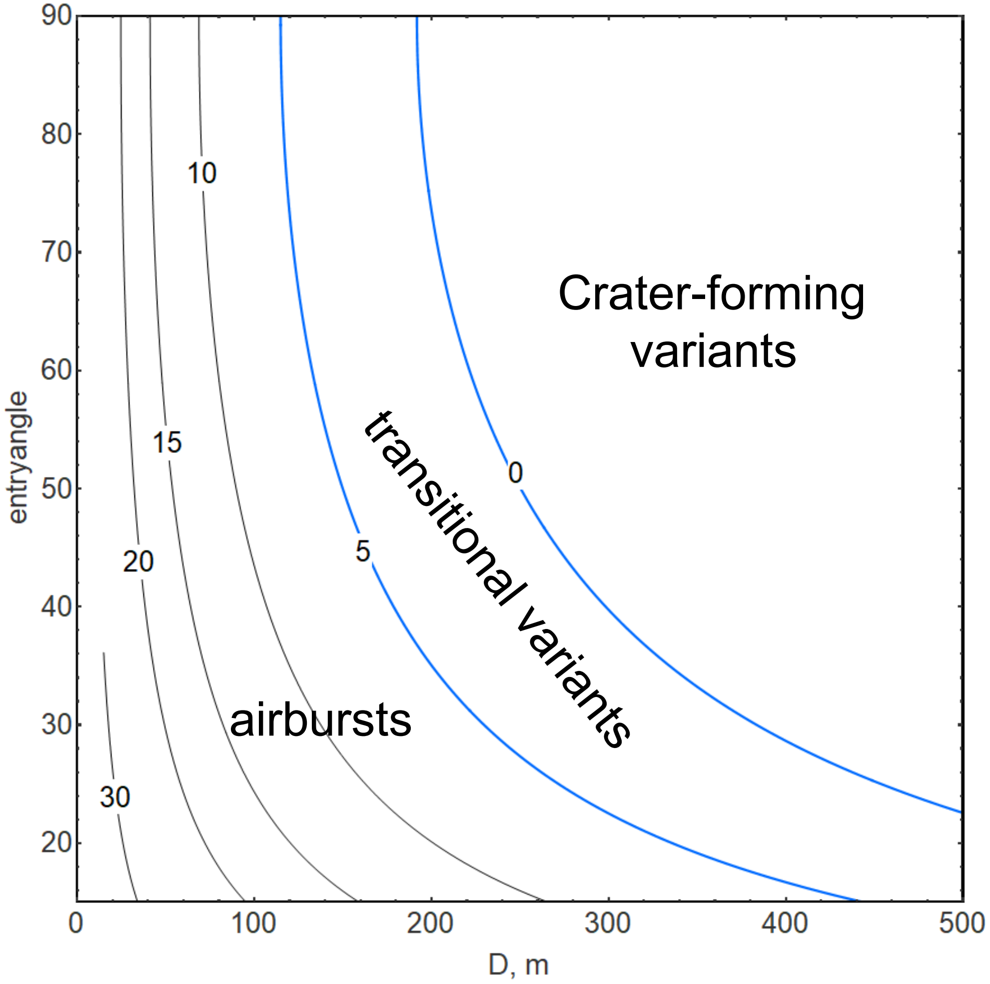
- for D~10-30 m the uncertainty in effective altitude may reach 10-15 km (Chelyabinsk, $TC_3$2008 and other cases) -(strength, fragmentation features etc)

*Determination of the height of the "meteoric explosion"*
*Shuvalov et al. Solar System Research 2016, V.50, I.1, pp 1-12*

# Effective airburst altitude – uncertainty area




Asteroids




Comets

$$H_{eff} = (-1.3 * H * \mathrm{Ln}(D * (\mathrm{Sin}[\alpha]/H) * (\rho/\rho 0)^{2/3}) + H)/1000$$

# Scaling relation for overpressure

$$\Delta p = el * m * \left(\frac{{E_k}^{1/3}}{{H_{eff}}^2 + x^2 + y^2}\right)^{pow}$$

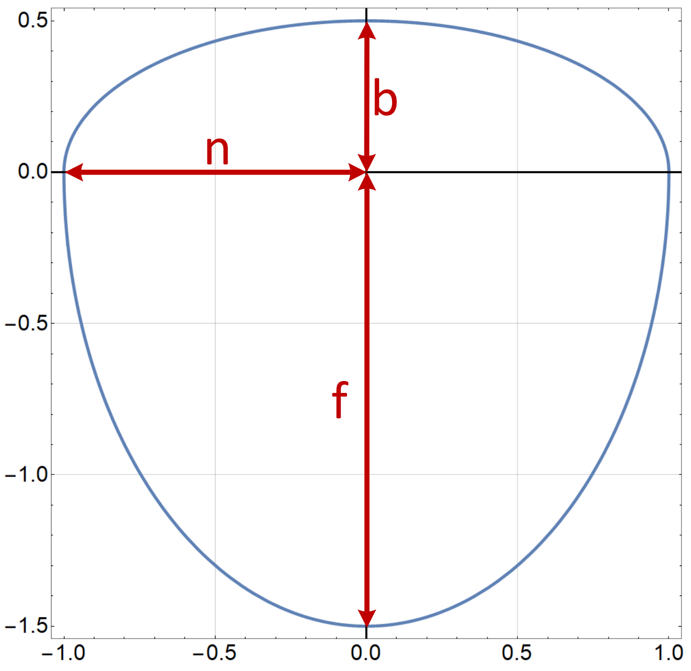
*x, y* – spatial coordinates
$el$– ellipticity parameter,
$E_k$ – kinetic energy of the impactor in kt TNT,
$H_{eff}$- effective height of point source,
$\phi$ – arctan(y/x).

<u>Airburst</u>

$$pow = 1.5$$
$$m = const$$
$$H_{eff} = function(\rho, D, \alpha)$$
$$el = el(\phi, n_{ab}, b_{ab}, f_{ab})$$
$$n_{ab} = fucntion(\rho, D, \alpha, V)$$
$$b_{ab} = fucntion(\rho, D, \alpha, V)$$
$$f_{ab} = fucntion(\rho, D, \alpha, V)$$

<u>Crater-forming</u>

$$pow = 1.4$$
$$m = function(E_k)$$
$$H_{eff} = 0$$
$$el = el(\phi, n_{cf}, b_{cf}, f_{cf})$$
$$n_{cf} = fucntion(\rho, D, \alpha, V)$$
$$b_{cf} = fucntion(\rho, D, \alpha, V)$$
$$f_{cf} = fucntion(\rho, D, \alpha, V)$$




the spatial heterogeneity

$$el(\phi, \dots) = \begin{cases} \frac{n * \mathrm{b}}{\sqrt{n^2 \mathrm{Sin}[\phi]^2 + \mathrm{b}^2 \mathrm{Cos}[\phi]^2}}, 0 \le \phi < \pi \\ \frac{n * \mathrm{f}}{\sqrt{n^2 \mathrm{Sin}[\phi]^2 + f^2 \mathrm{Cos}[\phi]^2}}, -\pi \le \phi < 0 \end{cases}$$

## Wind speed:

$$Vmax = \frac{330}{\gamma} * (p/p0 - 1) * \left(1 + \frac{\gamma + 1}{2 * \gamma} * (p/p0 - 1)\right)^{-1/2}$$

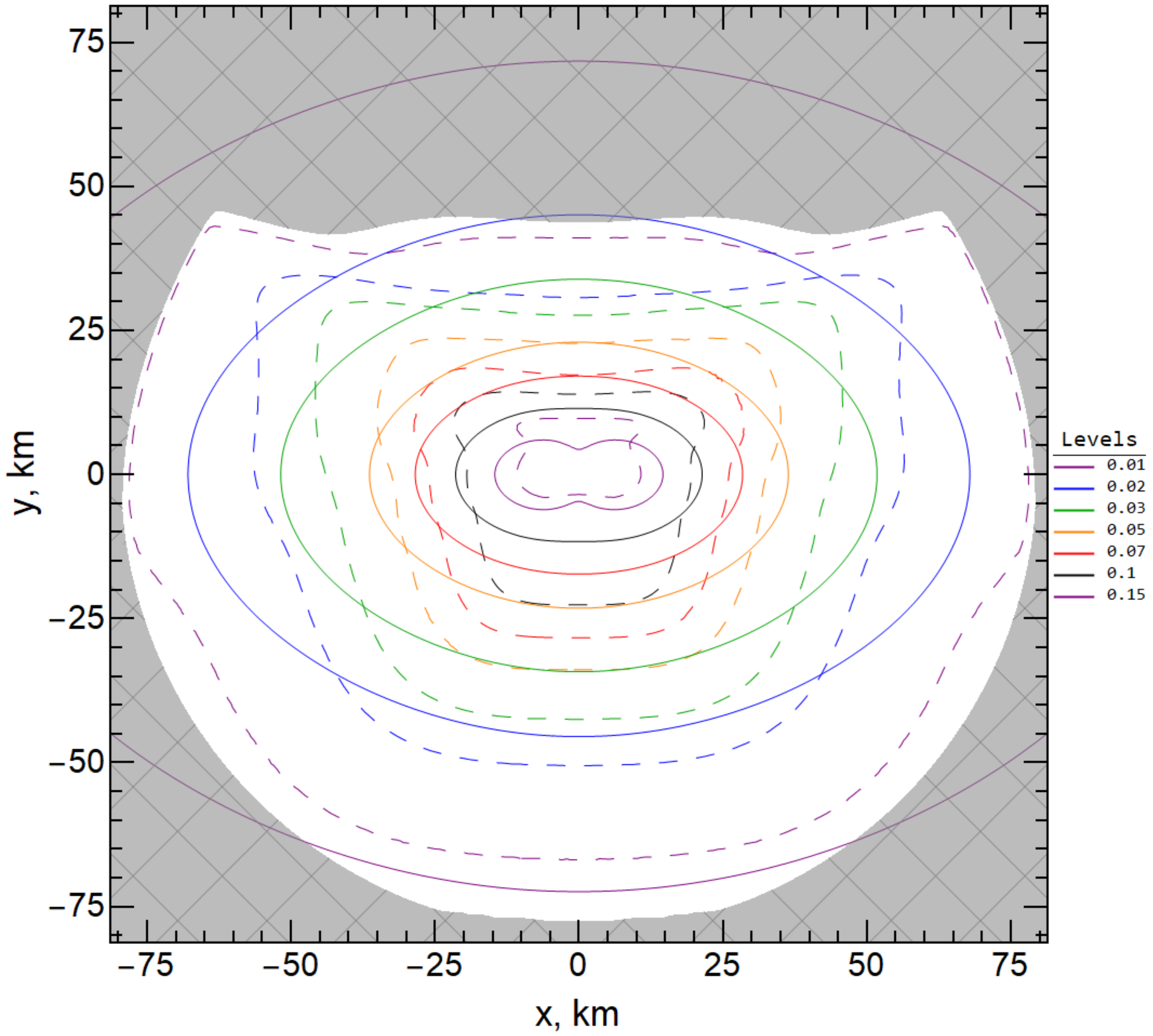
$\gamma$ - adiabatic index

$$vmax = \begin{cases} \frac{67.1 * {E_k}^{0.38}}{{H_{eff}}^{1.53}}, \rho = 1000\ kg/m^3 \\ \frac{40.51 * {E_k}^{0.39}}{{H_{eff}}^{1.45}}, \rho = 3320\ kg/m^3 \end{cases}$$

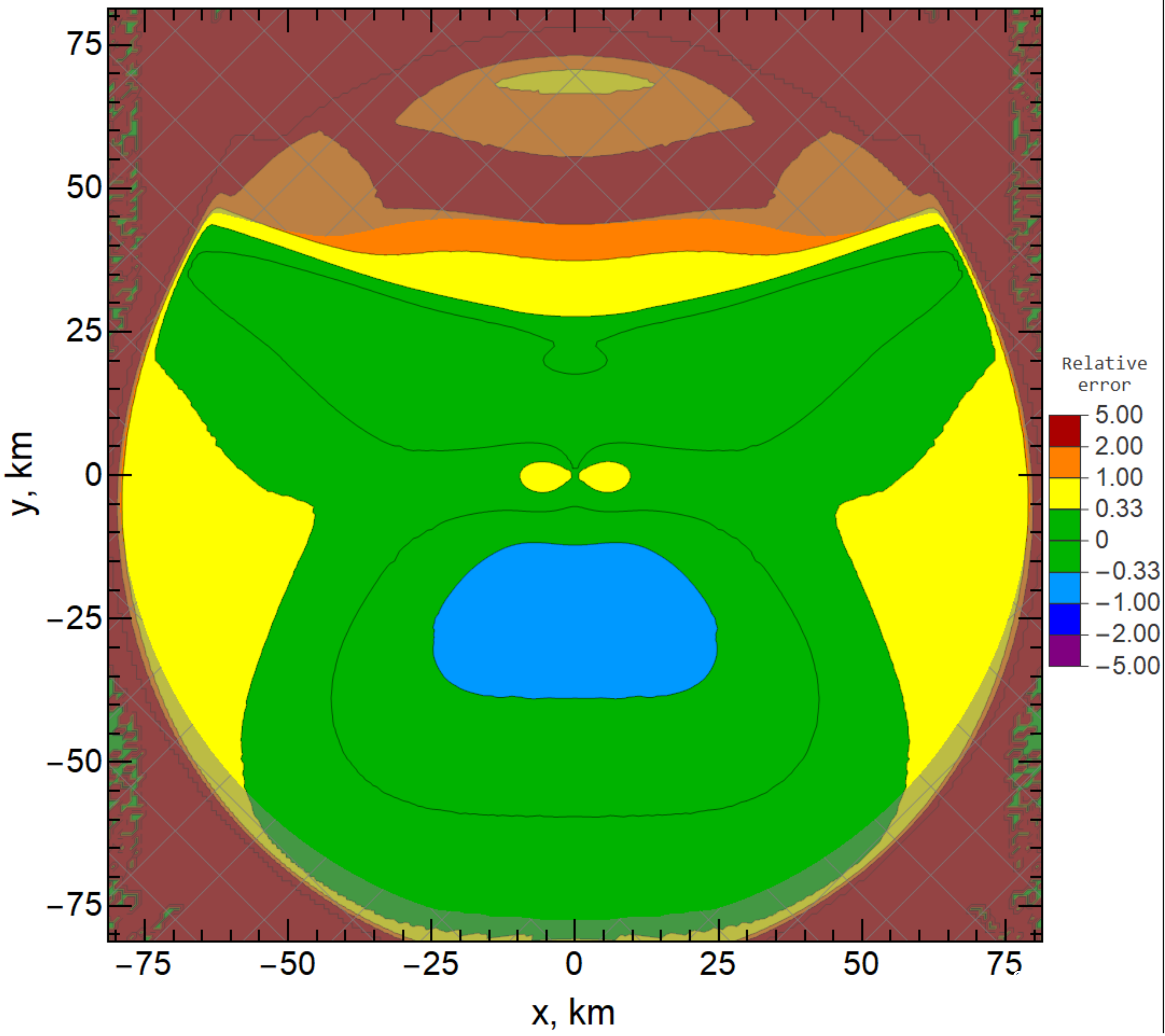
# Overpressure field with model and errors

Plot №17, D:50 m, $\alpha$:30°, V:15 km/s, $\rho$:3320 kg/m$^3$, E:5.8 Mt TNT

a 5.8
hetl 1.2
hetp 0.66
hetn 0.67




| | ErrorValue | Mean | Median | StandardDeviation |
|---|---|---|---|---|
| Relative squared error | 0.39 | 0.15 | 0.061 | 0.26 |
| Abs squared log error | 0.14 | 0.019 | 0.011 | 0.024 |



# Results comparison

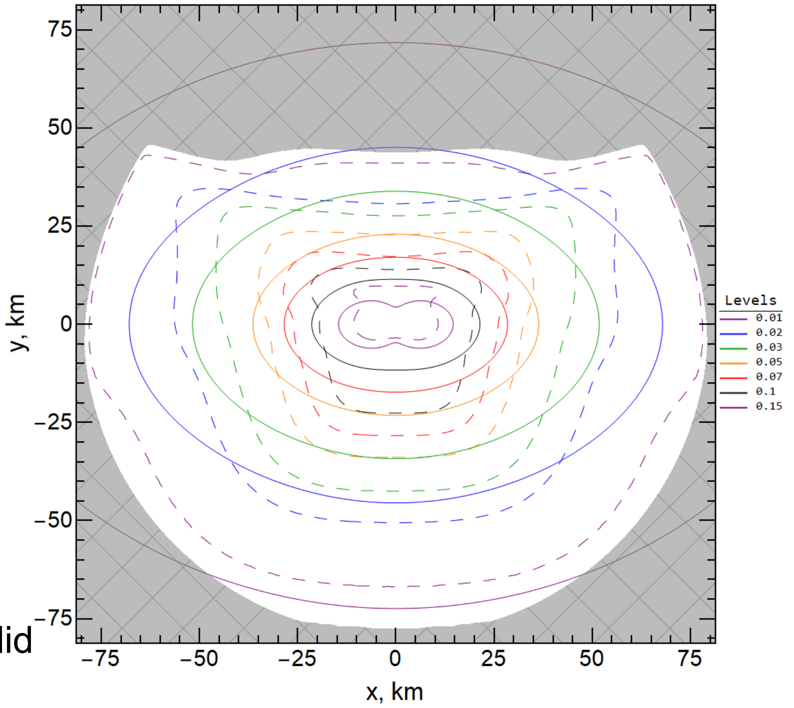
Our scaling relations
http://AsteroidHazard.pro

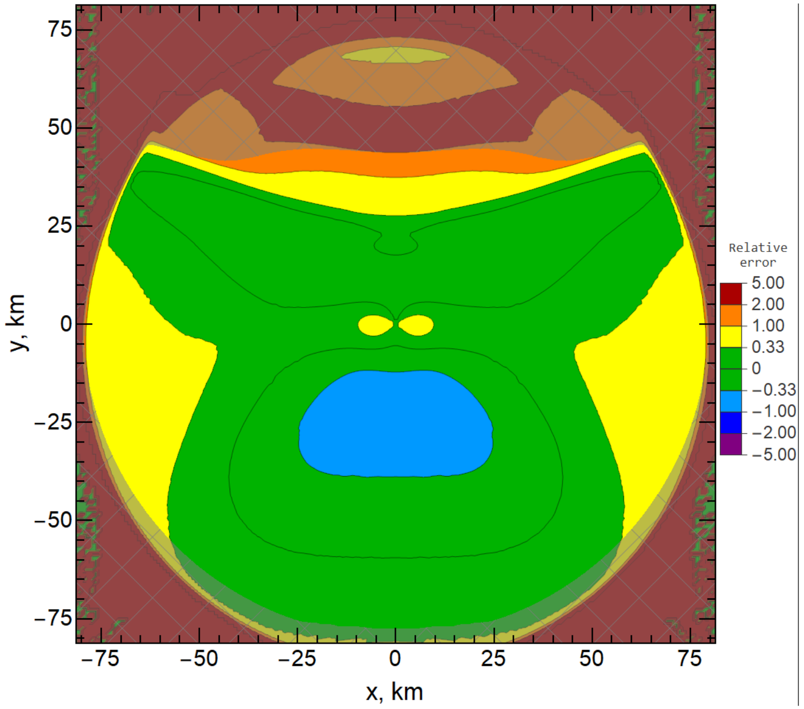
# D-50-30-15

density: 3320 kg/m$^3$
diameter: 50 m
fall angle: 30°
velocity: 15 km/s

Scalings-solid

Numerical modeling data - dashed

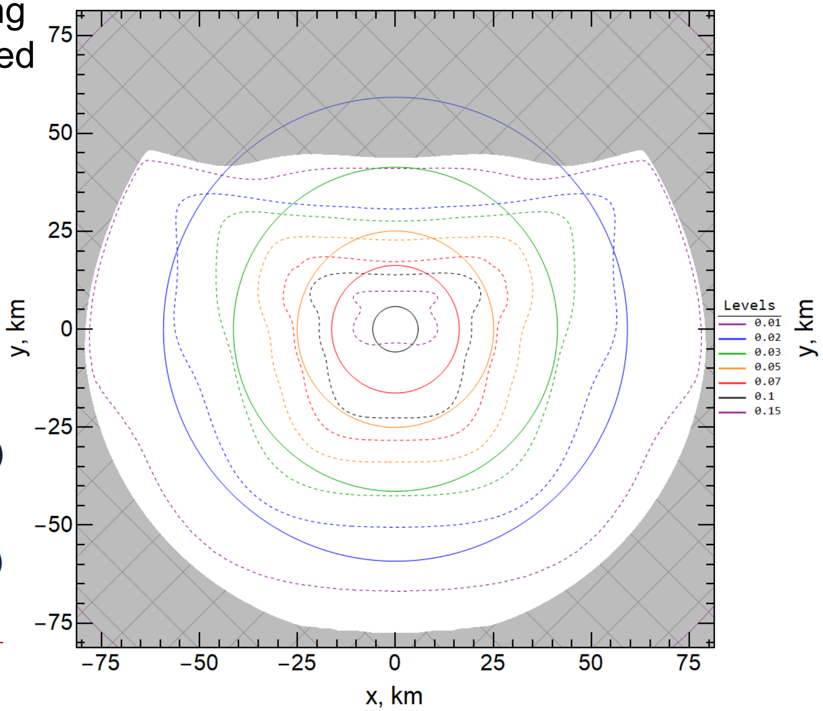


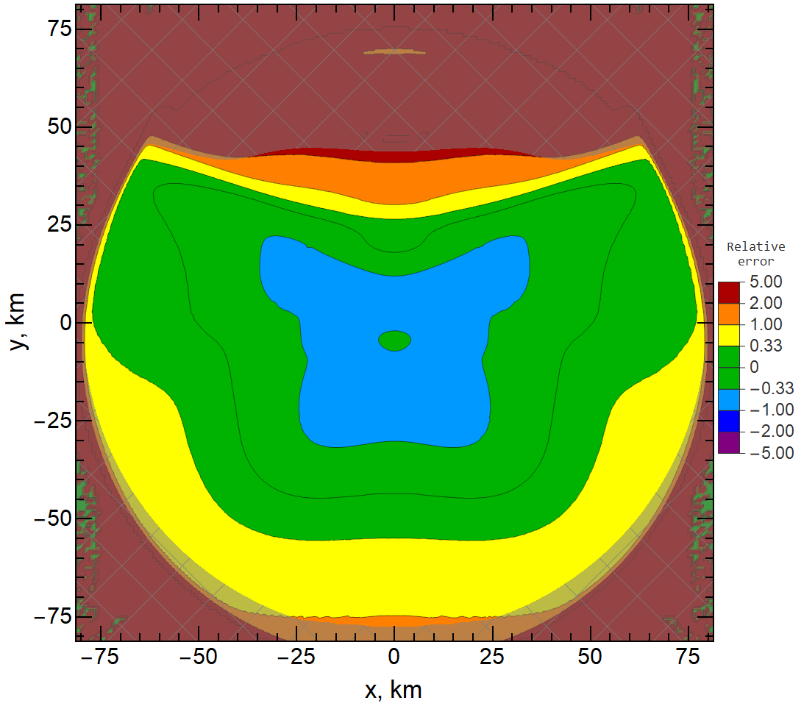




Collins et al. 2017

$$p(r) = 3.14 \times 10^{11}(r^2 + z_b^2)^{-2.6/2} + 1.8 \times 10^7 (r^2 + z_b^2)^{-1.13/2} \quad (7)$$

$$z_{b,50\%} = 25.7 - 7.83 \log_{10} E_{Mt} - 0.31(\log_{10} E_{Mt})^2 \quad (6b)$$



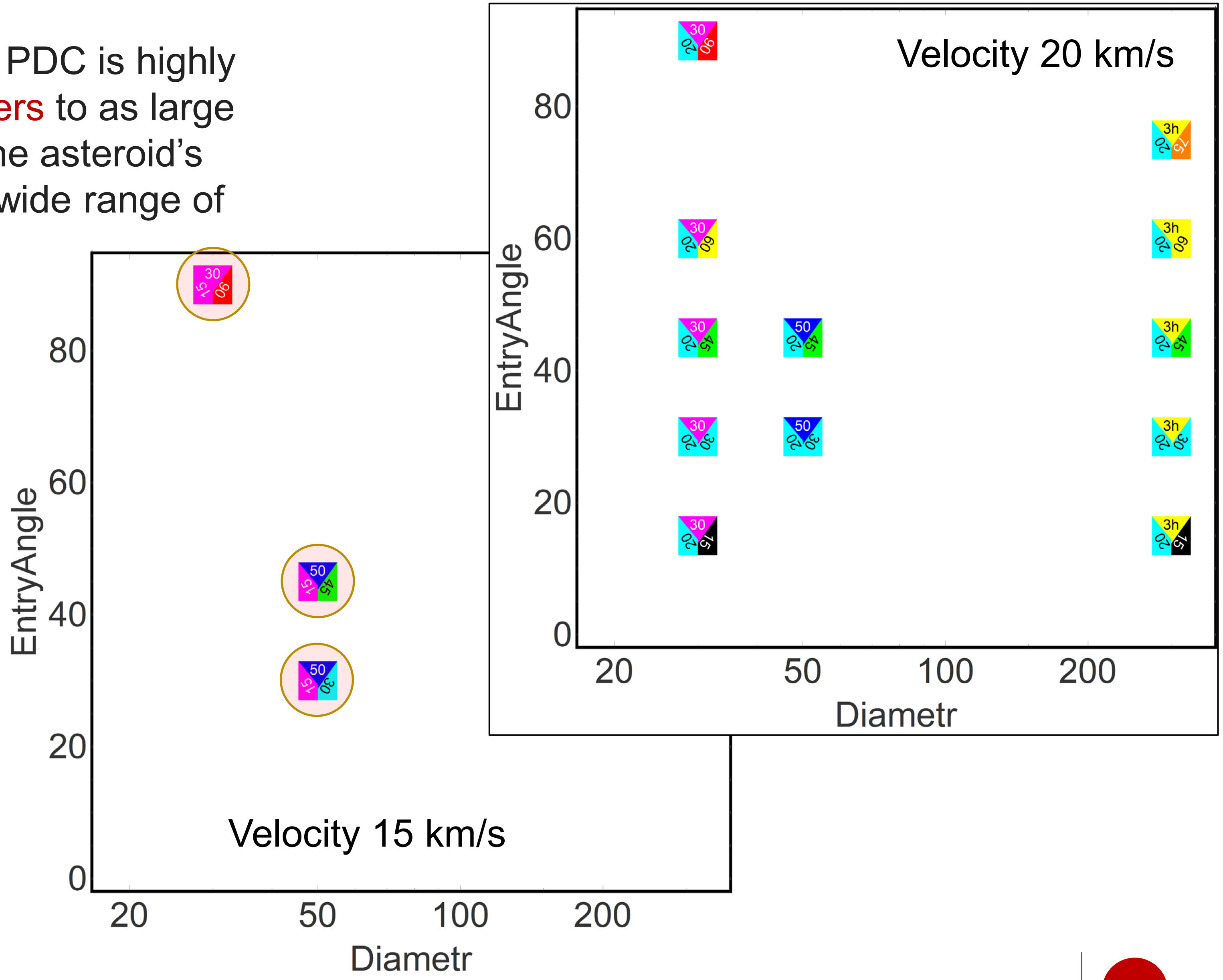



# Modeled variants in 2021 PDC excercise

«As mentioned previously, the size of 2021 PDC is highly uncertain, ranging from as small as 35 meters to as large as 700 meters. This estimate is based on the asteroid's brightness, its estimated distance, and the wide range of possible albedos (reflectivities).

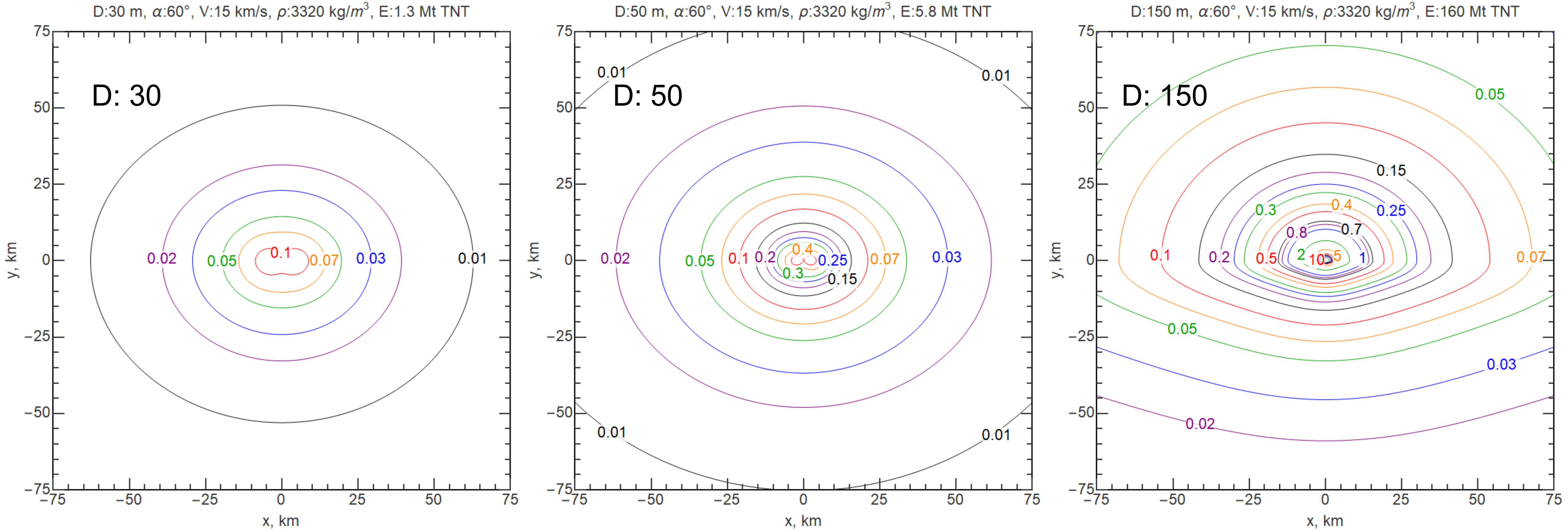
Little is known about other properties of the object, such as composition and density. As a result, the potential impact damage and population risk is also highly uncertain. Based on these estimates, the possible energy released on impact could range from 1.2 Mt to 13 Gt (TNT equivalent).

Velocity from 15.12 to 15.87 km/s
Entry angle from 0  to 90°



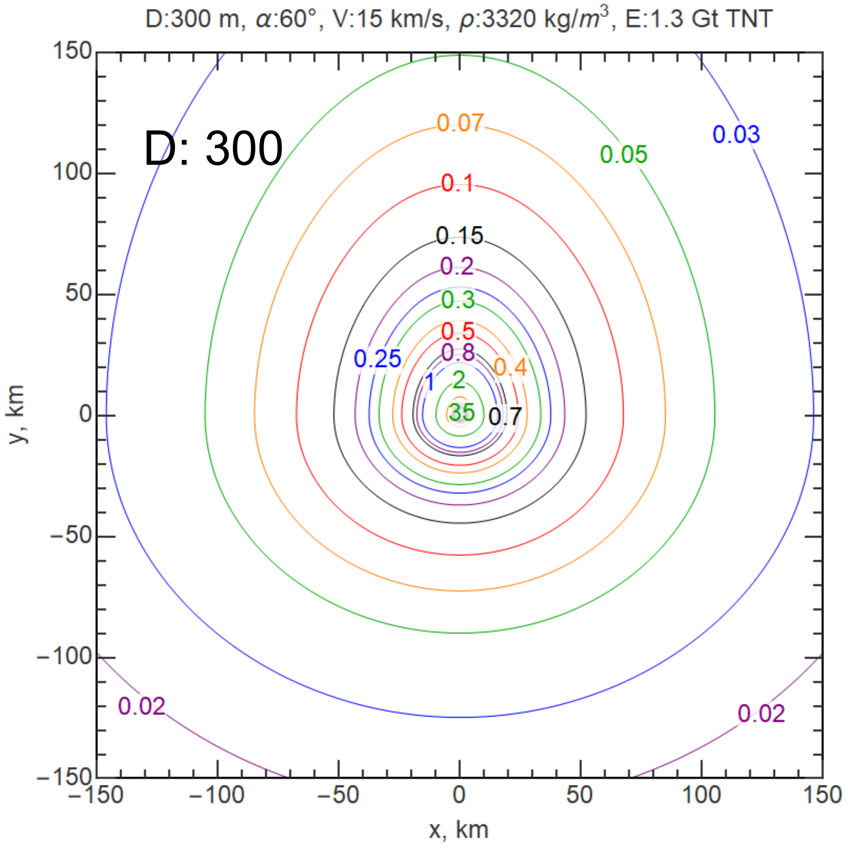
# Scaling relation for different diameters

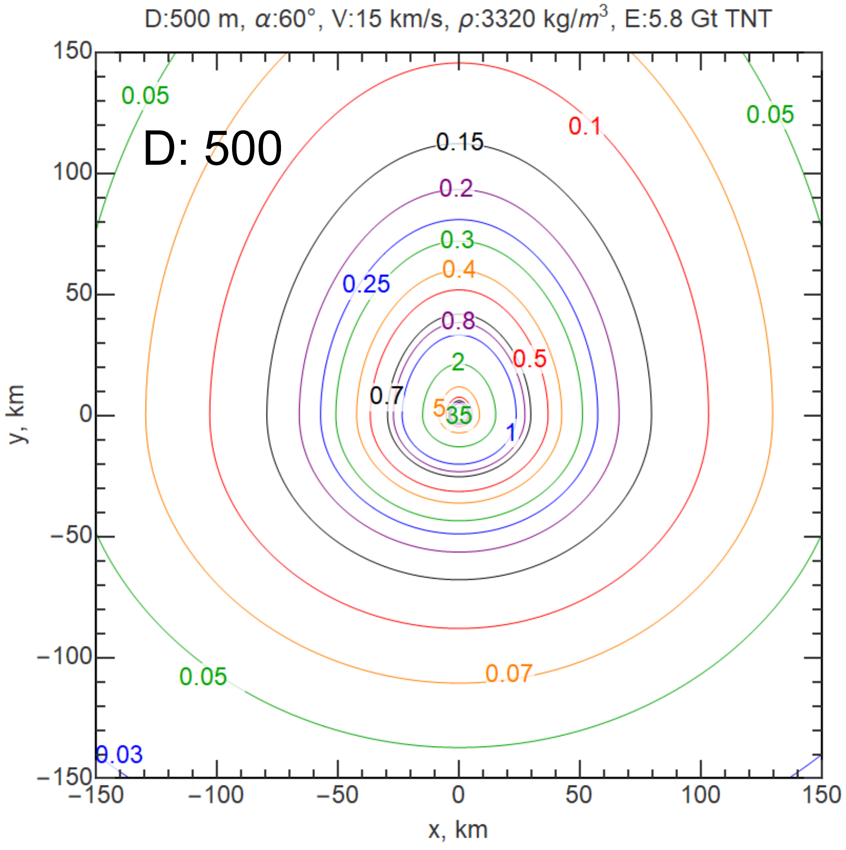
density: 3320 kg/m$^3$
diameter: various
fall angle: 60°
velocity: 15 km/s

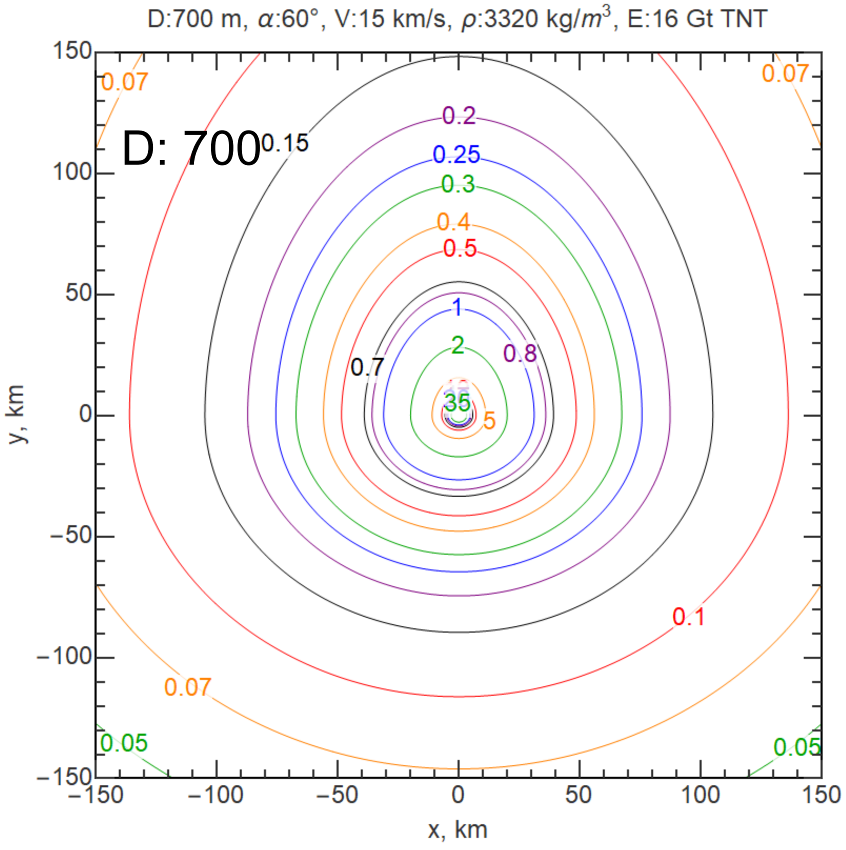


# Scaling relation for different diameters

density: 3320 kg/m$^3$
diameter: various
fall angle: 60°
velocity: 15 km/s

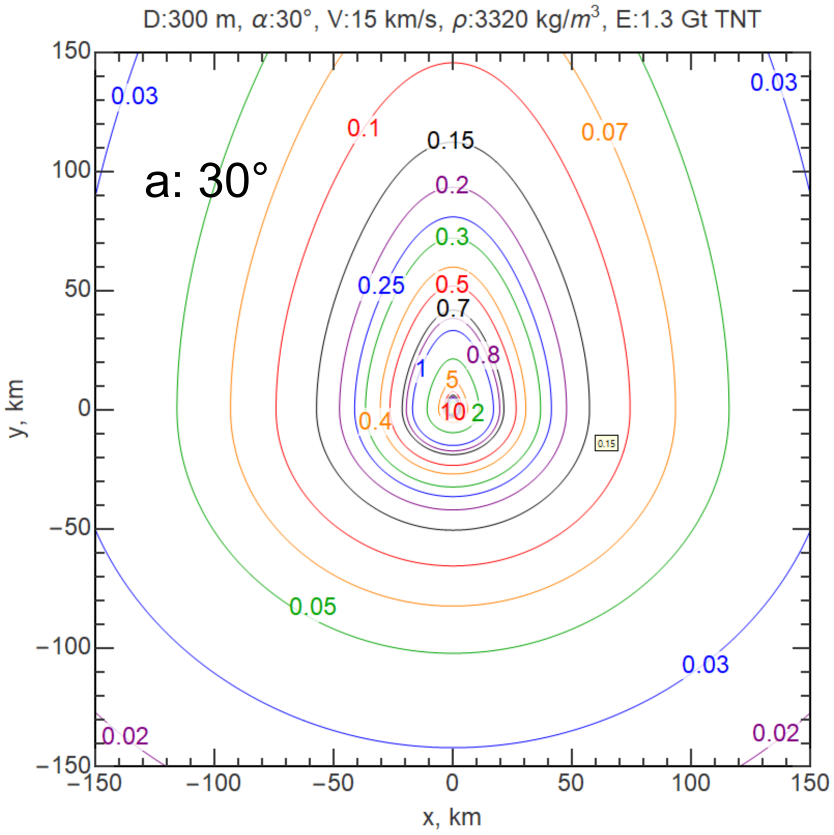


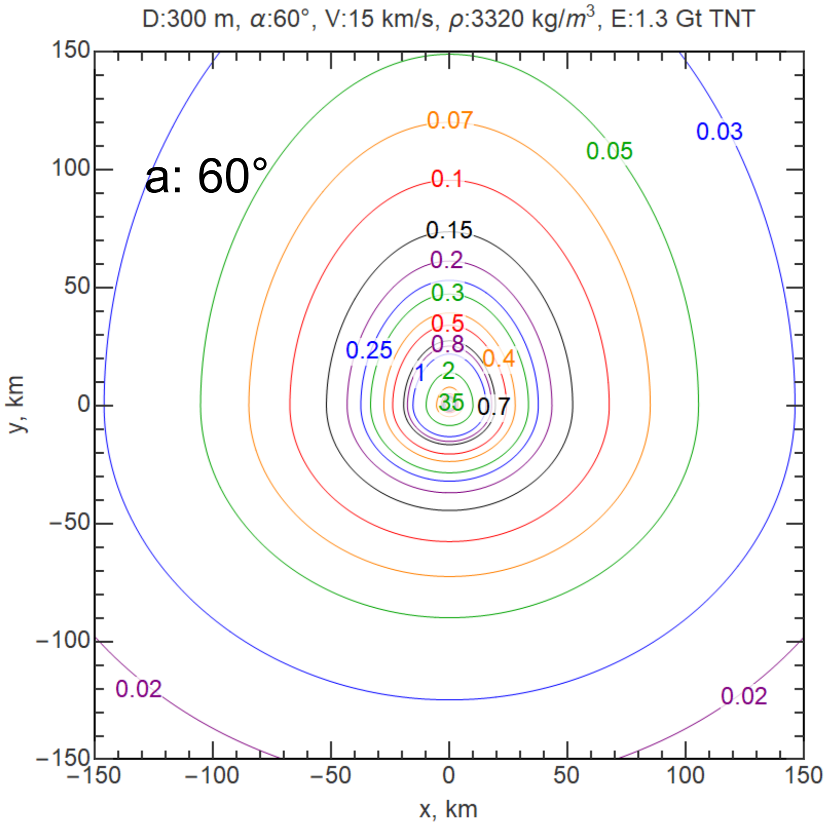



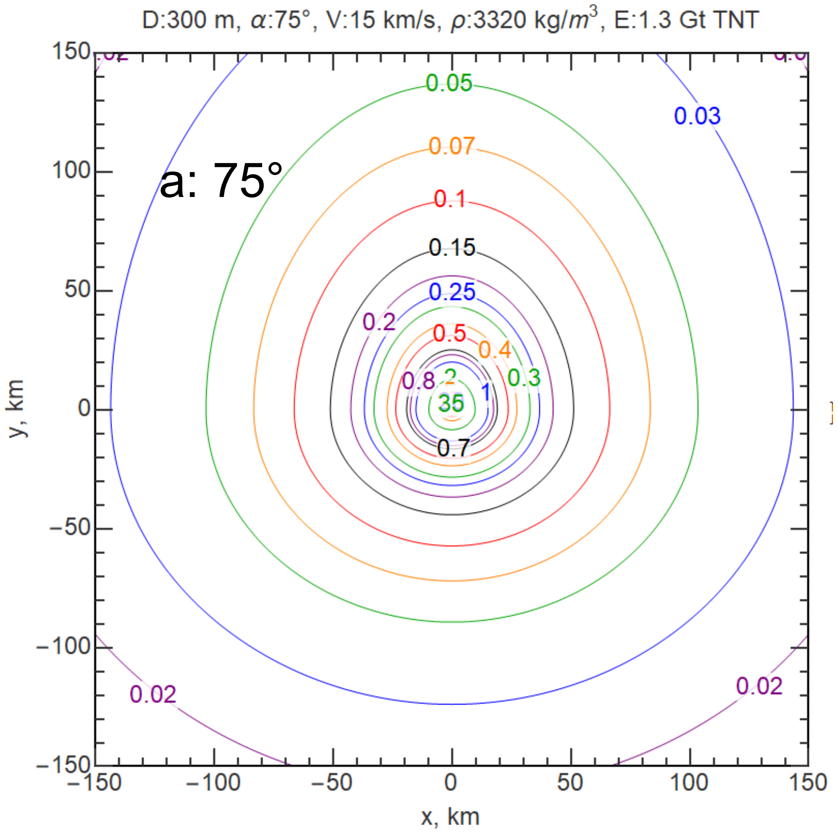



# Scaling relation for different entry angles

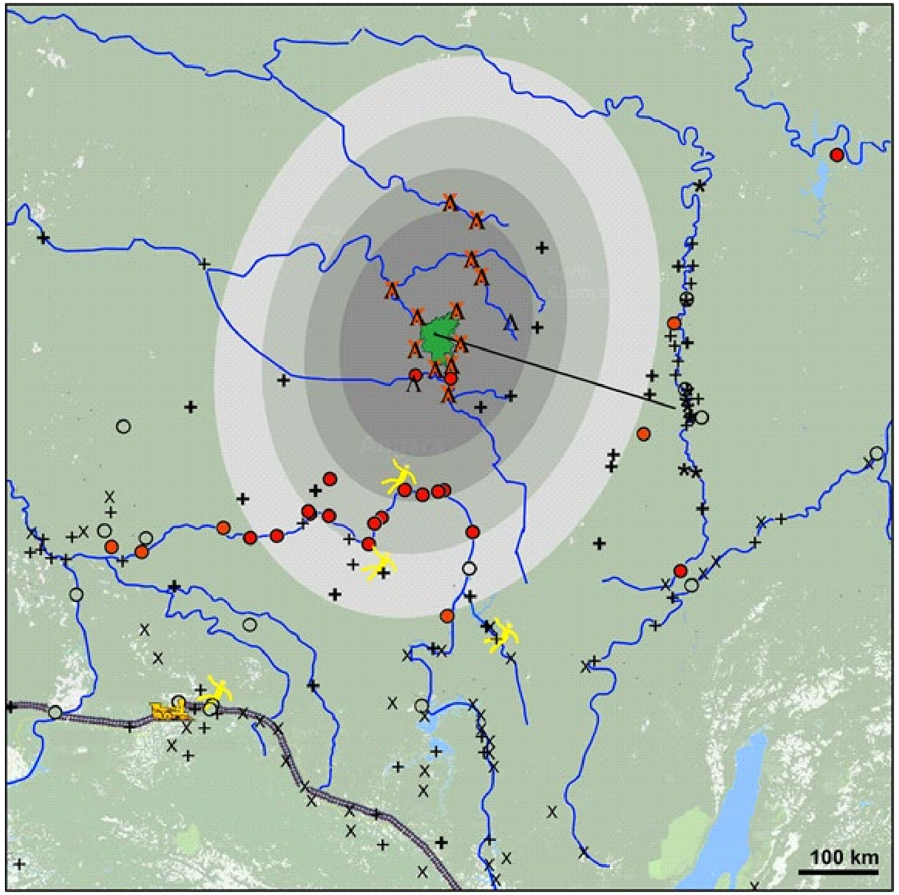
density: 3320 kg/m$^3$
diameter: 300 m
fall angle: various
velocity: 15 km/s

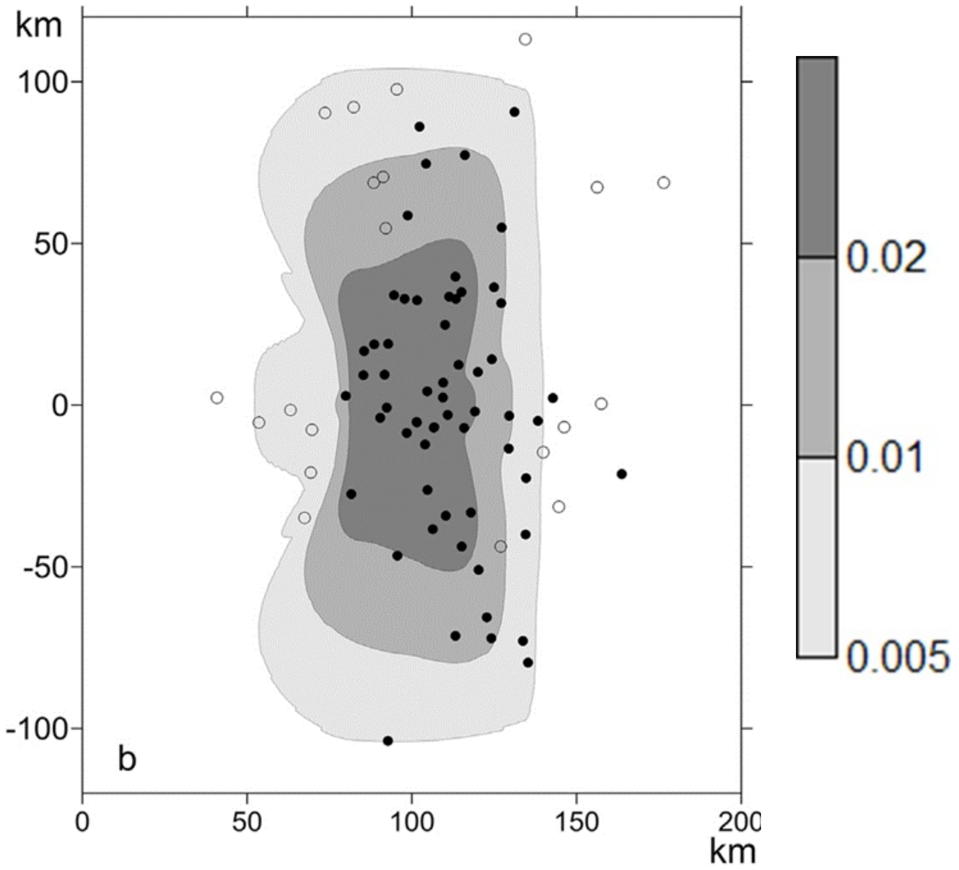


# Tunguska and Chelyabinsk events




Location map of eyewitness reports. .
Glass damage (filled red circle); glass rattled, not broken (o); chum destruction (Λ); heat and unconsciousness (orange X); people falling (person symbol).
Gray areas - ΔP based on scaling relations (12 Mt, 2000 kg/m3, 25°, 27 km/s).
Contours (from dark to light): ΔP ~1500, 1000, 700 and 500 Pa
*(Jenniskens et al. 2019)*

ΔP obtained in the frame of QL model *(Shuvalov et al.2017),*
black circles - reported damage, open circles – no damage.
Main characteristics of ΔP zones (>1 kPa) - satisfactory agreement
Scaling relations (not given) are also in agreement.

## Projectile Parameters

**Diameter:** *19 m*
**Density:** *3320 kg/m³*

## Impact Parameters

**Velocity:** *19.2 km/s*
**Entry Angle:** *18.3 °*

## Point of Effect

**Distance to the point of intersection of the trajectory with the Earth's surface:** *100.05 km*

BASIC ADVANCED

### Projectile Parameters

Diameter, m
19
15 m 150 m

Density, kg/m$^3$
3320
500 kg/m$^3$ comet asteroid 3320 kg/m$^3$

### Point of Effect

Distance to the point of intersection of the trajectory with the Earth's surface, km
100.05
0 km 500 km

### Impact Parameters

Velocity, km/s
19.2
10 km/s 72 km/s

Entry Angle, °
18.3
15 ° 90 °

Angle to Trajectory Projection, °
89.95
0 ° 360 °

RUN CALCULATIONS

### Projectile Parameters

**Diameter:** *19 m*
**Density:** *3320 kg/m$^3$*
**Energy:** *2.19 * $10^{15}$ J*
**Energy (kt TNT):** *5.23 * $10^2$ kt TNT*

### Entry Parameters

**Velocity:** *19.16 km/s*
**Entry Angle:** *18°*
**Latitude:** *54.45°*
**Longitude:** *64.56°*
**Azimuth:** *103°*

### Observation Point

**Zero Point:** *The point of intersection of the trajectory with the Earth's surface*
**Angle to Trajectory Projection, $\psi$:** *92°*
**Distance to the Zero Point, L:** *107 km*
**Distance Across the Trajectory Projection, $L_y$:** *107 km*
**Distance Along the Trajectory Projection, $L_x$:** *3 km*
**Latitude, $\phi$:** *54.04°*
**Longitude, $\lambda$:** *59.62°*

ALTER PARAMETERS

# RESULTS

| | | | |
|---|---|---|---|
| Airblast Wave | Overpressure: 0.0016 atm (0.16 kPa) | more... |
| Irradiation | Thermal exposure: 0.14 J/cm$^2$ | more... |
| Crater | No crater | more... |
| Ejecta | No ejecta | more... |
| Seismic effect | Magnitude: 3.4 | more... |
| Atmospheric disturbances | Peak amplitude of relative density oscillations at an altitude of 300 km: 0.52 | more... |

Impact Effects http://www.AsteroidHazard.pro

### Projectile Parameters

**Diameter:** *30 m*
**Density:** *3320 kg/m$^3$*
**Energy:** *5.28 * 10$^{15}$ J*
**Energy (kt TNT):** *1.26 * 10$^3$ kt TNT*

### Entry Parameters

**Velocity:** *15.00 km/s*
**Entry Angle:** *60°*
**Latitude:** *54.45°*
**Longitude:** *64.56°*
**Azimuth:** *103°*

### Observation Point

**Zero Point:** *The point of intersection of the trajectory with the Earth's surface*
**Angle to Trajectory Projection, $\psi$:** *180°*
**Distance to the Zero Point, L:** *50 km*
**Distance Across the Trajectory Projection, $L_y$:** *0 km*
**Distance Along the Trajectory Projection, $L_x$:** *-50 km*
**Latitude, $\phi$:** *54.46°*
**Longitude, $\lambda$:** *64.45°*

ALTER PARAMETERS

# RESULTS

## Airblast Wave

Overpressure: 0.013 atm (1.3 kPa)

...less

*Numerical simulations of a shock wave from the cosmic object impact provide possibility to suggest scaling relations for a value of maximal overpressure and its distribution on the surface, for maximal wind velocity behind the front and for a squares, where overpressure is larger than a fixed levelall values are determined based only on the properties of the impactor*

**Effective Altitude:** 12 km
**Maximal overpressure:** 0.12 atm (12 kPa)
**Distance to the center of a overpressure field from the point of intersection of the trajectory with the Earth`s surface:** 5.6 km
**Areas, at which chosen levels of overpressure exceed:**

- at 0.02 atm: 0.42 km$^2$
- at 0.05 atm: 0.07 km$^2$
- at 0.1 atm: 0.04 km$^2$
- at 0.2 atm: 0.04 km$^2$

**The value of the overpressure in the point of observation:** 0.013 atm (1.3 kPa)
**Maximum wind speed behind the shock front in the point of observation:** 3 m/s

## Irradiation

Thermal exposure: 1.0 J/cm$^2$

more...

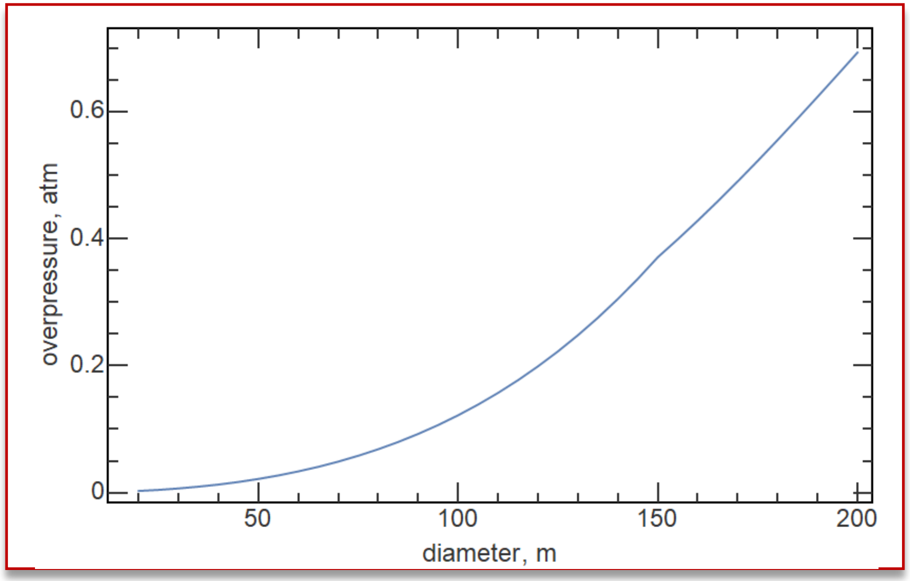
# API (application programming interface)

Wolfram Mathematica

HTTP post request

```
retrievedF[d_] := Import[URLRead[HTTPRequest["http://asteroidhazard.pro/en/api", <|"Method" → "POST", "ContentType" → "application/json" , "Body" → ExportString[
        <|
         "effects" → {"shockwave"},
         "impactor" → <|"diameter" → d, "density" → 3320|>,
         "entry" → <|"angle" → 18.3, "velocity" → 19|>,
         "point_of_effect" → <|
           "distance_across_trajectory" → 20,
            "distance_along_trajectory" → 5|>
         |>
        , "RawJSON", "Compact" → True] |>]],
     "RawJSON"]["shockwave"]["overpressure"]["value"];

In[=]:= data = Table[{d, retrievedF[d]}, {d, 20, 200, 5}];
```



# Summary

- The scaling relations for shock wave effects for 20 – 3000 m objects impact are presented. Scaling relations for overpressure, wind and some other characteristics are constructed.
- For the first time this scaling relations take into account spatial asymmetry induced by impact angle.
- Suggested scaling relations were compared with modelling results and existing observational data and demonstrated reasonable agreement
- Described scaling relations are implemented into web-based calculator
- PDC probable impactor parameters are very uncertain and its impact may result in consequences of different scale.

Thank you for attention

follow the updates on the site
AsteroidHazard.pro